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Hot/Wet Environmental Degradation of Honeycomb Sandwich Structure Representative of F/A-18: Discolouration of Cytec FM-300 Adhesive

A. Charon

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Aaron Charon

Airframes and Engines Division
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ABSTRACT

Bonded honeycomb sandwich panels, consisting of graphite-epoxy face-sheets adhesively bonded to a honeycomb core, are used on military aircraft such as the F/A-18 due to their high stiffness and low weight. Cytec FM-300 is the adhesive extensively used in bonding these composite structures. Water entering these structures can seriously degrade the adhesive bonds between the skin and core and within the core itself. Such degradation poses an issue for structural integrity as shown by a recent study conducted at AMRL. It is often difficult to know whether the internal structure has had prior exposure to water as the structure may dry yet the bonds may be degraded. It has been observed that in some failed components the adhesive changes colour from its original post cure green colour to a light/dark brown. A laboratory experiment was conducted on Cytec FM-300 adhesive to assess the colour change after exposure to a range of hot/wet environments typical of aircraft service. It was found that the adhesive undergoes differing colour changes depending on exposure conditions. The light brown colour seen in some failed components was produced when the relative humidity was >95% and the temperature exceeded 90°C for an exposure period in excess of 20 weeks. The study concludes that Cytec FM-300 adhesive that has changed colour to a light or dark brown colour has been directly exposed to a hot/wet environment.

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Executive Summary

The structural integrity of honeycomb sandwich panels can be permanently degraded if the internal structure is exposed to water. The integrity of the structure as a whole is largely dependent on the condition of the bonds between the honeycomb core and skin (fillet bond) and the bond at the nodes that make up the honeycomb (node bond). When extensive degradation of fillet and node bonds has occurred the structural integrity of the panel can be significantly compromised. Both the US Navy and Canadian Forces have experienced inflight failure of rudders due to this problem, and there is, therefore, a clear issue of safety of flight.

Cytec FM-300 film adhesive is used extensively in F/A-18 aircraft for bonding composite skins to honeycomb core. The characteristic colour of this adhesive is blue before curing and a thin layer at the surface discolours to a green colour after curing. Examination of a honeycomb sandwich beam recalled from a tropical exposure trial conducted at AMRL-Q in Innisfail Queensland, revealed an area of discoloured fillet adhesive on the underside of the graphite epoxy skin that had lifted from the core. The beam was also observed to have significant node and fillet bond degradation in the same area. The test beam was one of many beams used in a long term (9 years) environmental durability trial conducted at AMRL-Q in which the beams were exposed to a tropical environment where the average relative humidity was 83% and component surface temperatures could exceed 80°C. The mode of failure between the skin and honeycomb core was completely adhesive (ie. lack of adhesive adherence to these surfaces being bonded) indicating poor bond integrity. The colour of this discoloured patch of adhesive was a distinct light brown colour, quite different from the colour of the surrounding adhesive. The honeycomb core in this discoloured area showed characteristics typical of a structure degraded by water.

The main aim of this study was to see whether it was possible to use adhesive colour information as a guide to identifying internal structure that had previously been in contact with water. A small study into the effects of hot/wet environments on the characteristic colour of Cytec FM-300 adhesive was conducted. Several samples of cured FM-300 film adhesive were conditioned in various hot/dry and hot/wet environments for periods of up to 36 weeks. It was found that the light brown colour could only be reproduced in an environment where the relative humidity was at least 95% and temperature 90°C. Such an exposure environment would cause considerable degradation of the component in question. Thus adhesive colour can be used as a first

indication of whether structure may have been previously exposed to water and thereby for identifying compromised bond integrity.

Authors

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Aaron Charon graduated from the Royal Melbourne Institute of Technology with a Bachelor of Aerospace Engineering (Hons.) in 1994 after completing a Certificate of Technology in Aircraft, also from the same institution in 1990. On completion of his degree he held several short-term contracts within the major airlines of Australia including Qantas and Ansett Australia as technical support engineer and with Australian Defence Industries (ADI) as project engineer working on the Minehunter project. He later joined the Aeronautical and Maritime Research Laboratory in 1997 as research engineer primarily with the task of developing tools for detecting water within honeycomb sandwich structures. He is currently involved with research that examines the environmental degradation of bonded honeycomb sandwich structures.

Contents

1. Introduction

Honeycomb sandwich structures are used extensively on the F/A-18 aircraft for their stiff and lightweight properties. Some examples of this type of structure on the F/A-18 include the rudder, horizontal stabilizer and trailing edge flap. High temperature epoxy adhesives are used for bonding the composite structure. Cytec FM-300 is an epoxy adhesive that cures at 175°C and is commonly used for bonding the aluminium honeycomb core to the graphite/epoxy face-sheet. The structural integrity of these bonded sandwich structures depends largely on the strength of the adhesive bond between the skin and core (fillet bond) and the bonds that hold the honeycomb core together (node bonds). The environmental durability of these structures is generally very good but they are affected in service by water. Direct ingress of water into the internal structure either through damaged skins or by damaged seals, can cause permanent degradation of the adhesive bonds. Studies [1] have shown that direct water ingress can cause permanent losses of up to 30% in the flat-wise tension strength of the fillet bond. In addition to bond degradation, water can lead to corrosion of the honeycomb. A Canadian Forces F/A-18 experienced an in-flight failure of the rudder due to bond degradation caused by exposure of the internal structure to water. Water ingress is therefore a potentially serious problem. It is often difficult, however, to know whether the internal structure has had prior exposure to water. Moisture that may have previously occupied the internal structure can subsequently evacuate, leaving the structure dry yet in a degraded state.

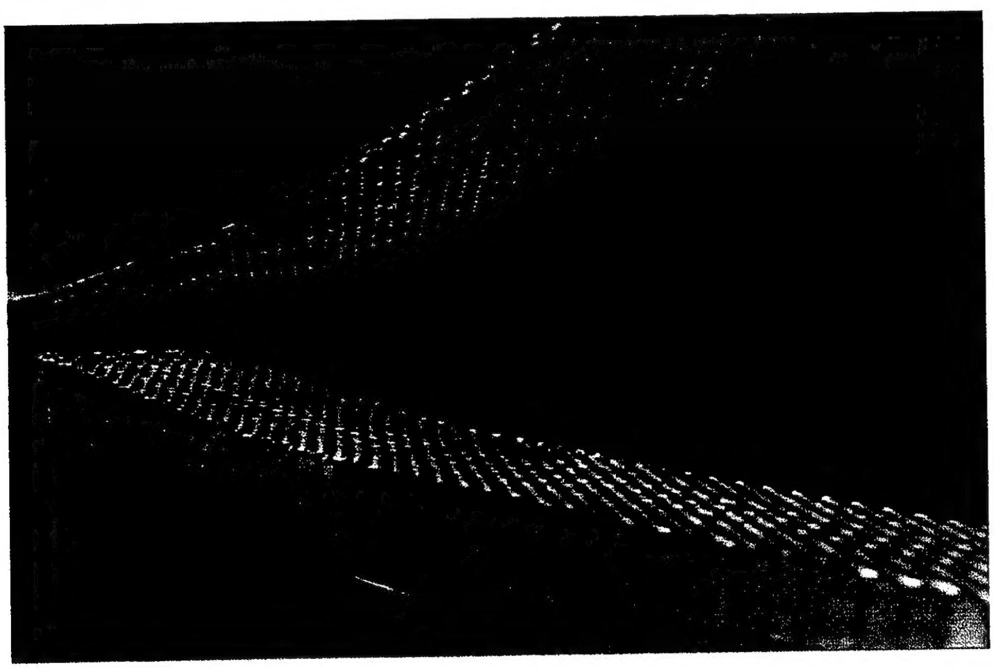


Figure 1 *Honeycomb sandwich beam recalled from AMRL-Q showing the carbon skin (top) disbonded from the core and a light brown colour of fillet adhesive at this part of the beam. The failure mode between the core and skin is purely adhesive.*

Examination of a failed honeycomb sandwich beam (Figure 1) recalled from a long-term tropical exposure trial at AMRL-Q, Innisfail Queensland, revealed a light-brown coloured area of FM-300 fillet adhesive. The beam was exposed to both mechanical loading and the tropical conditions at Innisfail. The Innisfail exposure site is reported [2] to have environmental conditions where the daily mean relative humidity is 83% and temperature 24°C. The surface temperature of specimens at this location under direct solar exposure has been measured at 82°C.

The construction of the beam recalled from Innisfail was representative of the F/A-18 structure and was one of many beams that were part of an environmental durability trial [2]. The recalled beam had been exposed to the tropical environment for a period of approximately 5 years. The specimen skin had failed at one section of the beam and lifted off from the core allowing moisture and water to enter the interior of the beam. The area of discoloured adhesive was seen on the inside of the lifted skin and was a distinct light brown colour (Figure 1), quite different to the colour of the surrounding adhesive. The core in this area exhibited severe node bond failures as shown in Figure 2 and some evidence of corrosion. The mode of failure between the core and the skin was purely adhesive (ie. lack of adhesive adherence to these surfaces). A second beam recalled from the same tropical exposure site revealed similarly discoloured adhesive but the skins on this sample remained intact to the honeycomb core as shown in Figure 3.

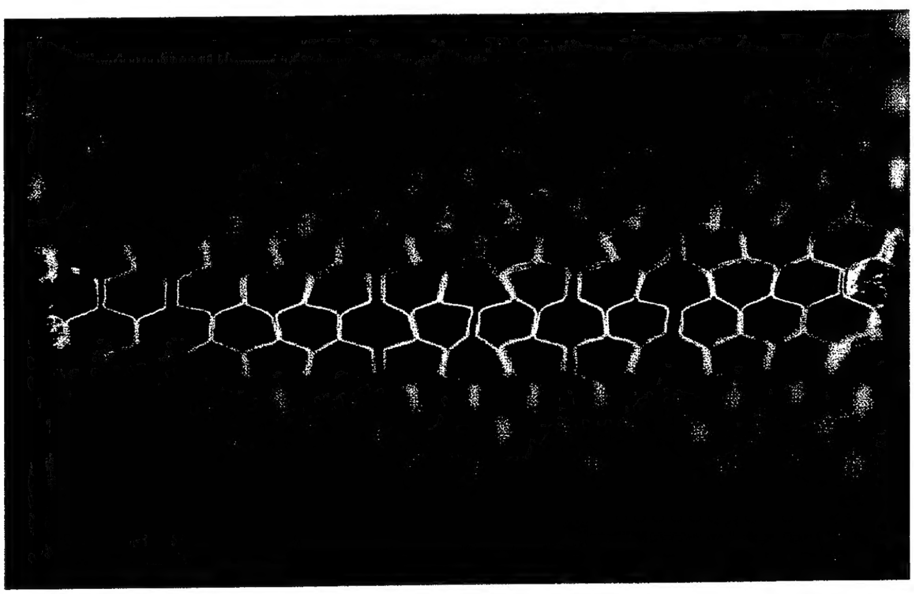


Figure 2 Honeycomb node bond separation along ribbon direction.

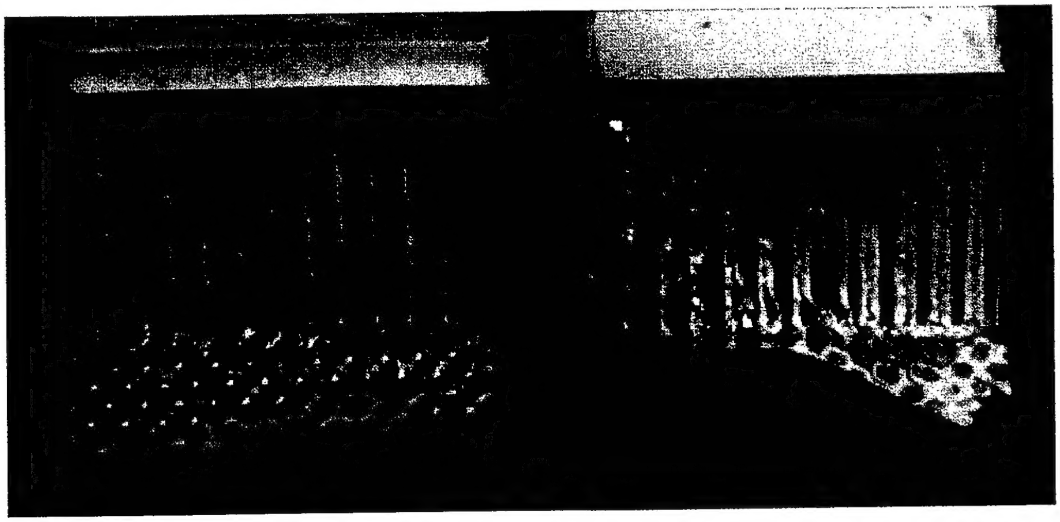


Figure 3 *A second example of discoloured adhesive on a specimen beam recalled from the AMRL-Q tropical exposure site located at Innisfail Queensland.*

Given that water ingress into honeycomb sandwich structures is a potentially serious problem and that water exposed structure is difficult to identify, it was thought useful if the brown adhesive colours seen in Figure 1 and Figure 3 were shown to be connected with water. If so, this colour information could be used to identify areas of structure that are likely to have poor adhesive bond integrity and suspect core as a result of prior water exposure.

A study into the effects of hot/dry and hot/wet environments on the characteristic colour of Cytec FM-300 film adhesive was conducted. Several samples of cured adhesive were conditioned in various hot/dry and hot/wet environments for period of up to 36 weeks. The changes in colour from a chosen reference colour were recorded periodically. The aims of the program were:

a) to reproduce the distinct light-brown colour seen on the subject beam, in a laboratory environment and establish any possible connection with exposure to water.

b) to establish whether a relationship exists between adhesive colour and environmental exposure so that adhesive colour information can be used as a guide in identifying previous exposure history.

c) to better understand the type of environment that causes the mode of failure seen on the AMRL-Q beam.

2. Experimental Procedure

2.1 Characteristic and Reference Colour of FM-300 Adhesive

The characteristic colour of Cytec FM-300 adhesive appears blue in the uncured off-the-shelf form as shown in Figure 4. Coloured dyes are added to the adhesive by the manufacturer to enable easy identification. When the adhesive is cured in air at the manufacturers recommended cure temperature of 175°C, the adhesive undergoes a colour change where the blue colour shown in Figure 4 changes to green. This may be caused by oxidation of the pigment in the adhesive. If the adhesive is cured in the complete absence of air, the adhesive does not undergo a colour change. The characteristic colour shown in Figure 4 merely loses its blue lustre and the general colour remains faded but blue as shown in Figure 5. During the manufacture of honeycomb sandwich panels, where the face-sheets are bonded onto the honeycomb core in an autoclave, the air contained in the honeycomb cells is sufficient to cause the adhesive to change colour. A thin film on the fillet adhesive changes colour to green as shown in Figure 6. The faded blue colour shown in Figure 5 is therefore only achievable if the adhesive is completely starved of air during curing, such as when cured between glass plates or when the adhesive is pinched between the panel face-sheet and the honeycomb. This cured but somewhat faded colour (Figure 5) of FM-300 adhesive achieved in the above way will be taken as the reference colour in this study. All changes in adhesive colour during this study will be compared to this reference colour.

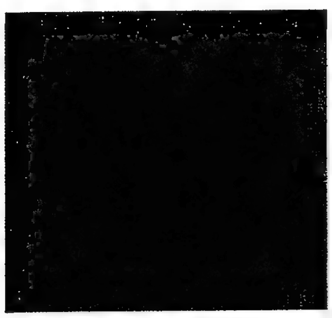


Figure 4 Characteristic colour: Colour of Cytec FM-300 adhesive in uncured off-the-shelf form.

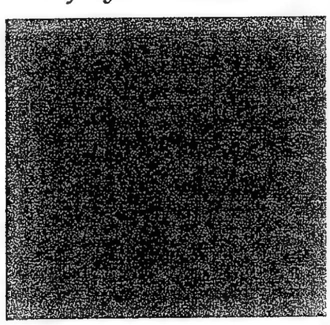


Figure 5 Reference colour: Colour of Cytec FM-300 film adhesive obtained when cured in the absence of air such as when cured between two glass plates.

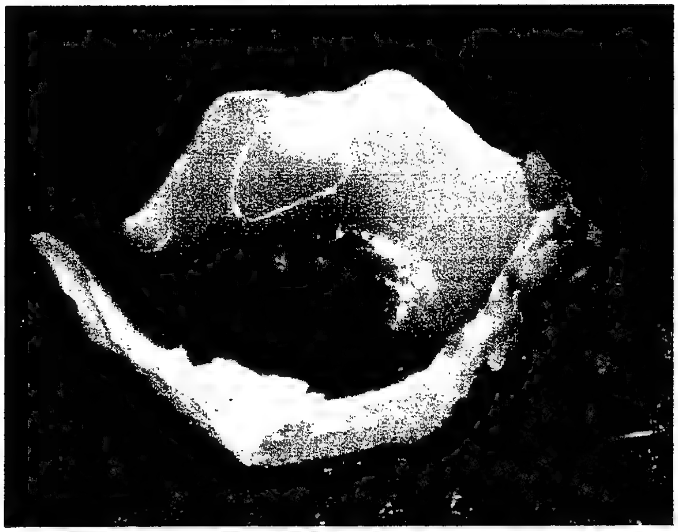


Figure 6 A sample of cured fillet adhesive showing a discoloured green film at the surface.

2.2 Test Specimen Design and Manufacture

The experimental program involved exposing two types of specimens to various hot/dry and hot/wet environments. In the first type, only the edges of the specimen were to be exposed. This was to simulate moisture diffusion through the edge of an adhesive layer as would exist for a well-sealed component. The second type of specimen exposed the entire surface of the adhesive to simulate the condition where the face-sheet has peeled from the core (eg: as shown in Figure 1) and water is able to freely enter the component. In preparing both types of specimen, the main effort was focused on guarding the adhesive from air during the curing process so that the reference colour shown in Figure 5 could be obtained. The size of the FM-300 adhesive samples used in both specimen types was 90 x 90 millimetres square.

(i) Surface exposure specimens. It was difficult to manufacture this type of specimen. In most attempts, air could not be prevented from coming in contact with the adhesive surface. A green discoloured layer formed on the adhesive surface during curing at 175°C. A trial to cure the samples in a vacuum oven was unsuccessful. The vacuum contained in the oven drew out pits and voids in the adhesive as the adhesive softened. A satisfactory specimen was produced when the samples were sandwiched between a piece of glass plate and Teflon. The Teflon (unperforated, 1.5 mm thick section) provided a non-stick surface and was ideal to preserve one face of the adhesive. The edges of the set-up were sealed using a vacuum bagging sealant (Mastic) and flash-break tape during the curing process. A small mass (approximately 0.5 kilogram) was applied on top of the sandwich assembly during curing to provide a positive pressure. The lay-up of the surface exposure specimen is shown in Figure 7.

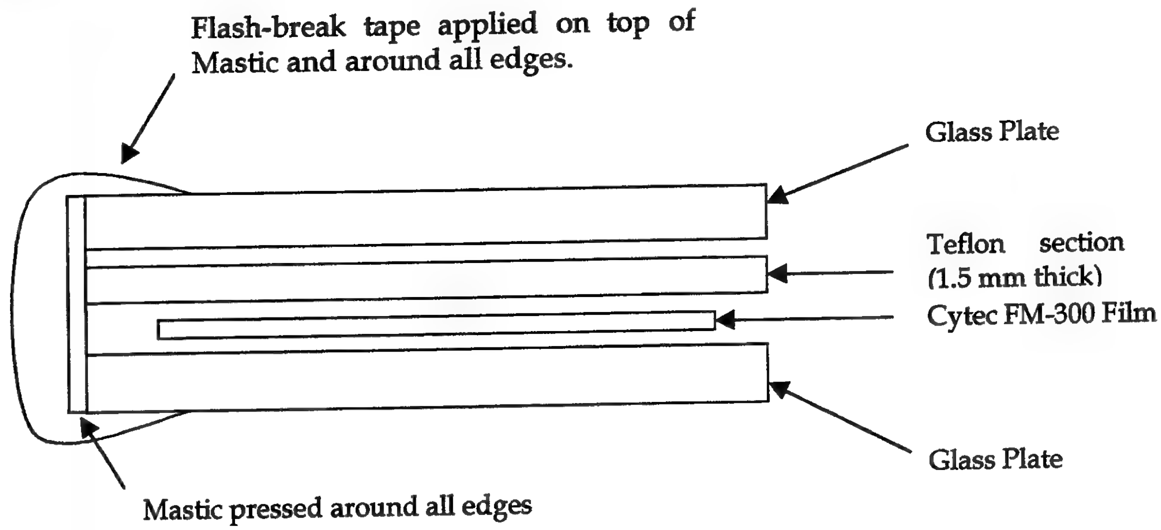


Figure 7 Manufacture and lay-up of surface exposure specimen

(ii) Edge only exposure specimens. As this type of specimen required only the edges of the adhesive to be exposed, the method for manufacture was relatively easy. As there was no requirement to keep a free adhesive surface, the adhesive film was sandwiched and cured between two glass plates. The glass plates bonded to the adhesive and guarded the adhesive against air exposure. The lay-up for this type of specimen was therefore identical to that shown in Figure 7 but did not include Teflon.

2.3 Environmental Conditioning

The specimens were exposed to a range of hot/wet environments as shown in Table 1 and Table 2.

Hot-Dry Environments: Exposure temperatures of 50°C, 90°C and 100°C were used. These temperatures are considered to be in a range representative of F/A-18 service as specimen surface temperatures in excess of 80°C have been recorded at tropical test sites such as Innisfail, Queensland.

Hot-Wet: A combination of hot/wet conditions were used to establish simulated tropical exposure. These included tests conducted at relative humidity levels of 85% and 95% and temperatures of 70°C, 80°C and 90°C. The 70°C, 85% relative humidity condition was produced by a Heraeus Votsch climatic test cabinet (HC 4055). Conditions at relative humidity 95% and temperatures 70°, 80° and 90°C were produced by placing specimens above a hot water bath. The respective temperatures were measured and maintained at the specimen surface.

2.4 Colour Recording of Test Specimens

The means for recording colour was an issue in this study and for the preparation of this report. Techniques that would enable more accurate identification of colour to a known standard were examined. Due to the many different colours appearing across the surface of such small samples, these techniques were found unsuitable and not particularly necessary for the purpose of this report. The aim of this report is to merely highlight complete and significant changes in colour. For example, from blue to green and from green to brown. It is not necessary to identify the different shades of these colours accurately.

Recording of specimen colour was conducted at time 4, 8, 16, 25 and 36 weeks. The colour of the specimens were scanned directly using a digital scanner. The image colour, contrast and brightness were enhanced on screen to resemble the colour state of the samples as closely as possible. The image was then printed and compared to the colour of the actual specimen. Where the required colour was unable to be produced using the scanner, an image of the specimen was taken using a digital camera. Although the colours were enhanced to represent the specimens closely as possible, it is recognised that the colours will undergo some change when transferred electronically from different computers and printers. The colours presented at Appendix A are therefore a close and not exact representation of the colours found in experiment. All changes in specimen colour were compared to the reference colour of FM-300 adhesive shown in Figure 5.

3. Results

Progressive changes in colour of the specimens are shown in Appendix A for each exposure condition. The colour of FM-300 cured in the absence of air (as seen in Figure 5) is provided in each result set as a reference colour for comparison. Exposure conditions for both the edge exposure and surface exposure study are presented in Table 1 and Table 2 respectively. An example of the colour change experienced by FM-300 adhesive during the manufacturers recommended cure cycle is presented for reference in section 3.1.

Table 1 Exposure conditions for edge only specimens

Edge Exposure only (double sided glass plate)

Temperature °C	Relative Humidity	Specimen #
70	85%	13
100	0	9
70	95%	11

Table 2 Exposure conditions for single sided specimens

Surface Exposure (single sided)

Temperature °C	Relative Humidity	Specimen #
70	85%	14
70	95%	12
80	95%	15
90	95%	16
90	1.1%	17
50	16.7%	1
100	0	2

3.1 Colour of Fillet Adhesive Layer – As Cured

Hot/Dry - 175°C FM-300 adhesive film is cured at a temperature of 175°C for 60 minutes. During the curing process, the adhesive forms fillets that bond the honeycomb core to the skin as seen in Figure 9. The small quantities of air contained in the honeycomb cells during panel bonding causes the adhesive to change colour to a light green colour. This discolouration is restricted to a thin layer at the surface of the adhesive and is probably due to oxidation of the adhesive pigment. If a tensile test is used to pull the skin off from the honeycomb core subsequent to the curing process, these discoloured areas of adhesive will appear as small hexagons as seen in Figure 8. The discoloured hexagonal areas are separated by channels of fillet tear-out which appear blue. The blue areas are starved of air during bonding as they are pressed between the honeycomb foil and skin and should therefore be of a colour similar to that shown in Figure 5.

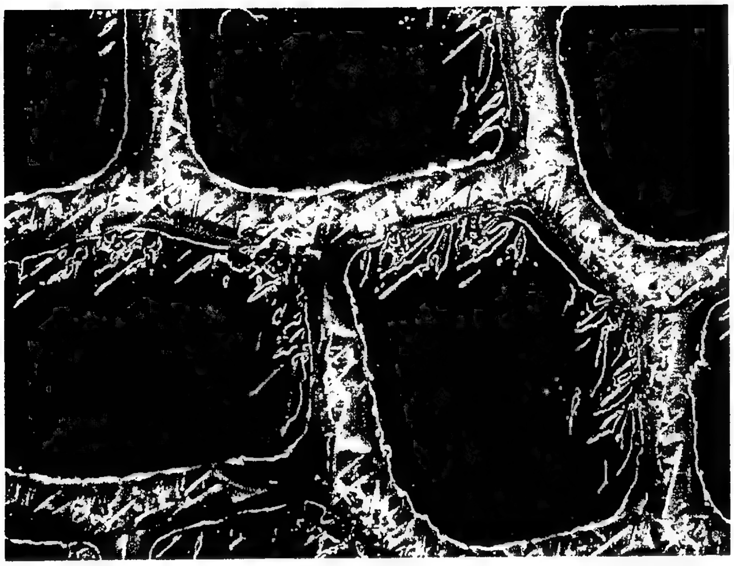


Figure 8 View looking down on a cured FM300 bondline located between the honeycomb core and face-sheet. The honeycomb has been pulled off from the skin during mechanical testing revealing the fillet tear-out areas (appearing a blue colour compared to the air discoloured green areas).

Figure 9 Cross sectional view of the adhesive fillet bond on a newly manufactured panel showing the thin green layer of discoloured adhesive.

3.2 Surface Exposure Specimens

The following observations were made after exposure to the conditions outlined in Table 2.

Hot/Dry - 50°C, 16.7% RH Specimen 1 was exposed to a hot/dry environment of low relative humidity and a temperature of 50°C for approximately 16 weeks. The overall colour of the specimen remained blue. When compared to the reference colour of cured Cytec FM-300 adhesive, it was of duller appearance. There was no evidence of green or brown discolouring.

Hot/Dry - 100°C, 0% RH Specimen 2 was conditioned in an environment at zero relative humidity and temperature of 100°C for a period of 13 weeks. The colour of this specimen had a dull army green appearance. The colour had changed significantly from the reference colour and there was no resemblance to blue. The sample did not look brown in appearance.

Hot/Wet - 70°C, 95% RH Specimen 12 was conditioned in an environment at a relative humidity of 95% and a temperature of 70°C for a period of 36 weeks. The overall colour of the specimen appeared faded to a lighter blue/green colour but there was no evidence of any brown colours. In addition, the centre of the specimen appeared faded when compared to the sample edges.

Hot/Wet - 70°C, 85% RH Specimen 14 was conditioned in an environment at a relative humidity of 85% and a temperature of 70°C for a period of 36 weeks. The temperature at the surface of the specimen was the same as that for specimen 12, although the relative humidity was 10% less. Again the specimen showed no sign of colour change to a brown colour. The colour was similar to that of specimen 12 (blue/green) but appeared significantly darker. The colour appeared uniform across the whole surface and had not faded at the centre of the specimen.

Hot/Wet - 80°C, 95% RH Specimen 15 was conditioned in an environment at a relative humidity of 95% and a temperature of 80°C for a period of 36 weeks. The colour of this sample appeared quite different to that of both specimens 12 and 14. The specimen showed colour changes to that of a very light brown colour. The colour was seen to be non-uniform and patchy. The overall colour of the specimen, when compared to specimens 12 and 14, appeared to be a light green/brown colour. Some localised areas contained darker spots of brown. The entire surface colour appeared to be in a transition from light green/brown to a uniform light brown colour. Some areas of the surface appeared to be a very light green/white colour.

Hot/Wet - 90°C, 95% RH Specimen 16 was conditioned in an environment at a relative humidity of 95% and a temperature of 90°C for a period of 36 weeks. There were only two colours seen on this specimen and this was light and dark brown. The light brown colour occupied the centre area of the specimen and resembled the brown colour seen on the AMRL-Q beam shown in Figure 1. The dark brown colour was seen along the edges of the specimen and was a very deep brown colour that occupied an area 10 millimetres wide along the edges of the specimen. This dark brown colour seemed to be spreading in towards the centre of the specimen. It appears that with time, the whole of the surface would become a uniform dark brown colour. The brown colours on the surface of this

specimen first appeared in a lighter shade after 16 weeks of exposure. The discolouration then intensified as time past from 25 to 36 weeks. The centre of the specimen always appeared lighter than the darker brown along the edges of the specimen.

Hot/Dry - 90°C, 1.1% RH Specimen 17 was conditioned in an environment at very low relative humidity and a temperature of 90°C for 36 weeks. The colour was uniform across the specimen surface and appeared a light green/brown colour but more green than brown. Although the colour contained some brown, the overall colour did not resemble the colour of the fillet adhesive seen on the AMRL-Q beam. The colour was significantly different to that of specimens 12 and 14.

3.3 Edge-Only Exposure

Results for this type of specimen were limited. The only result available was that for specimen 9 which was exposed to a hot dry environment at 100°C for approximately 5 weeks. The hot/wet results were not valid. The moisture contained in the hot/wet conditions, caused the bond between the glass and the adhesive to fail allowing full surface exposure of the specimens. No further hot/wet tests were carried out.

The following observations were made after exposure to the conditions outlined in Table 1.

Hot/Dry - 100°C, 0% RH The majority of the surface of this specimen, with the exception of the very edges, was of the reference blue colour. The edges along the whole of the sample discoloured to a green colour very similar to the colour of specimen 2. The width of the discoloured edge was not more than 1 millimetre.

Progressive colour changes of each specimen are shown in Appendix A.

4. Discussion

The characteristic uncured colour of Cytec FM-300 adhesive shown in Figure 4 undergoes significant colour changes when exposed to various environmental conditions. During honeycomb sandwich panel manufacture, where the adhesive is cured for 60 minutes at 175°C, small quantities of air contained in the honeycomb cells causes a green discoloured film at the surface of the adhesive as seen in Figure 6. This green discolouration may be caused by oxidation of the pigment particles in the adhesive. When the adhesive is cured in the absence of air, such as when cured between two glass plates, the adhesive loses its original blue lustre and turns a dull blue but still maintains its general blue colour (as seen in Figure 5).

Apart from the changes in colour observed during panel manufacturing processes, adhesive test samples conditioned as part of the experimental program changed colour to various shades of blue, green and brown when exposure to a variety of both hot/dry and hot/wet environments. Providing the conditions were sufficiently hot and wet, there appeared to be

a general trend where the reference colour initially underwent a colour change to a dull blue then to green and then to brown after extended exposure times. In hot/dry conditions where the temperature is below 80°C, the specimen does not change colour but may dull.

A significant observation was made when specimens 12 and 15 were compared. The colour of these specimens were completely different yet they were exposed to very similar conditions. The colour of specimen 12 appears light green/blue in colour with no brown content. Specimen 15 does not look blue and the overall colour appears to be a light green colour progressively changing to a brown colour. These two specimens were exposed to the same relative humidity of 95% but different temperatures. Specimen 12 was at a temperature of 70°C and specimen 15 at 80°C. It appears that the level of both temperature and humidity play a significant role in FM-300 adhesive discolouration. The appearance of specimen 15 suggests that changes in overall colour to brown first appear at a temperature of 80°C.

The exposure conditions of specimen 12 were identical to the conditions used by a recent flat-wise tension test program [1] for conditioning honeycomb sandwich test coupons. This study measured the strength of the bond that exists between the honeycomb core and the skin on specimens that were conditioned in an environment where the relative humidity was 95% and the temperature 70°C. Water was free to enter the specimens through holes drilled through the skins. The flat-wise tension strength of these specimens, after 36 weeks of conditioning, had degraded by about 30%. The colour of the fillet adhesive seen on these specimens showed no sign that the colour was changing to brown and was a dark green colour as shown in Appendix A (Plate 12). This comparison shows consistency in the observed colours.

Specimen 16 was the only specimen that produced colours similar to those colours seen on the AMRL-Q beam shown in Figure 1. At the exposure period of approximately 36 weeks, the light brown colour seen at the centre of specimen 16 was similar to the brown colour seen on the AMRL-Q beam. Beyond this period of exposure, the whole of the specimen began to take on a darker shade of brown. The edges of the specimen changed to a very deep brown and the centre appeared to be taking on this same dark shade of brown as time passed.

Specimens that were exposed to elevated temperature only (ie. no humidity), appeared to undergo colour changes that were uniform across the surface of the specimen. This was also the case with specimens exposed to hot/wet conditions at a relative humidity of up to 85%. Once this level of relative humidity was exceeded, the specimen discoloured non-uniformly. At relative humidity levels of 95% and above, the colour at the centre of the specimen appeared to fade. This centre area was significantly lighter than the remainder of the specimen. This effect was seen on specimens 12, 15 and 16. Specimen 15 showed an additional effect where darker localised spots of brown appeared across the surface of the specimen quite apart from the specimens overall change in colour to brown. This may be due to random condensate pooling on the surface.

5. Conclusion

The findings of this study are applicable only to structure that has been bonded using Cytec FM-300 structural adhesive.

This study shows that temperature, humidity and time play an important role in the FM-300 adhesive discolouration process. Both hot and wet conditions are needed for the colour of the adhesive to change to brown. Specimens conditioned in hot/dry environments alone did not change colour to resemble those colours seen on the AMRL-Q beam. No brown discolouration was observed at temperatures less than 80°C and relative humidity less than 95%. Given that a high humidity environment (95% RH) exists, the temperature must be at least 80°C for FM-300 adhesive to change colour to brown.

FM-300 fillet adhesive that appears brown in colour is likely to have been exposed to water or high levels of humidity at high temperatures for long periods of time. The results from this study indicate that the failed area of the AMRL-Q beam, was very likely exposed to high levels of moisture at temperatures above 80°C. These conditions are considered achievable [2] at the Innisfail exposure site. It is possible that the honeycomb core in this area of the recalled beam was partly filled with water.

Cytec FM-300 adhesive discolours at the surface to a light green colour if exposed to even small quantities of air during curing. The air contained in honeycomb cells of honeycomb during curing at 175°C is sufficient to cause this discolouration. Provided the interior of honeycomb sandwich structures are maintained dry after initial manufacture, the colour of the fillet adhesive layer should appear a green colour as shown in Figure 6.

6. Recommendations

The colour of Cytec FM-300 adhesive should be noted at any time where the opportunity arises, either during routine maintenance or repair operations.

While the tests carried out in this study have not been exhaustive, the appearance of light or dark brown coloured FM-300 adhesive does suggest the need for further investigation.

In such cases, further investigation may involve the measurement of the adhesion strength between the honeycomb core and the skin in the discoloured region of adhesive. This may be carried out using a portable pull-off adhesion tester (PATTI Model 110 or similar) as per ASTM D 4541-95$^{\epsilon 1}$ that measures the adhesion strength of the skin to the honeycomb core by removing a plug of skin from the core.

7. References

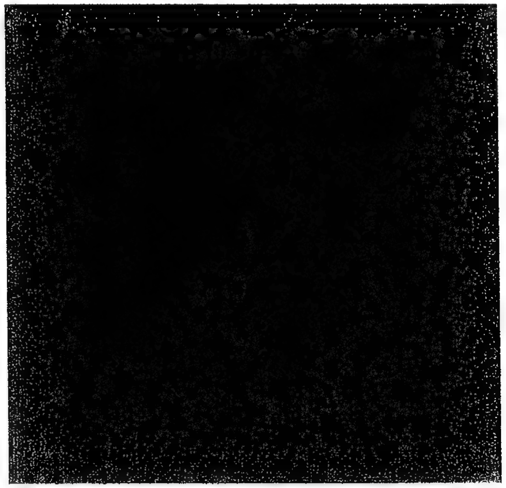
1. *T.C Radke, A.Charon and R.Vodicka, 'Hot/Wet Environmental Degradation of Honeycomb Sandwich Structure Representative of F/A-18: Flat-wise Tension Strength', DSTO-TR-0908, AR-011-146.*

2. *R.J Chester and A.A. Baker, 'Environmental Durability of F/A-18 Graphite/Epoxy Composite', Polymers and Polymer Composites, Vol. 4, No. 5, 1996, pp315-323.*

8. Acknowledgments

The author acknowledges the input of T.C Radtke and R. Vodicka in reviewing and contributing to this report.

Appendix A:



Reference Plate
Colour of Cytec FM300 film adhesive when cured in the absence of air (between glass plates).

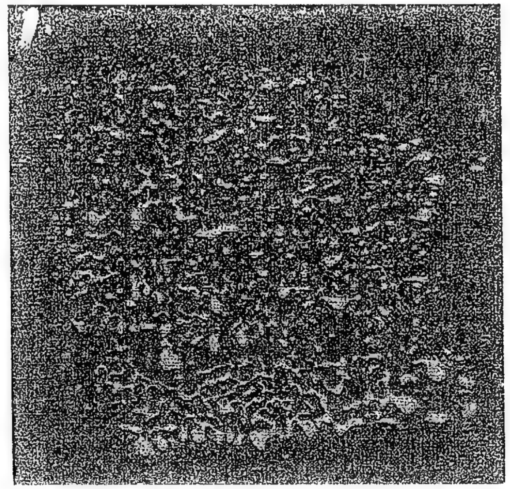


Plate #1
Exposed to 50 °C dry environment for approximately 16 weeks.

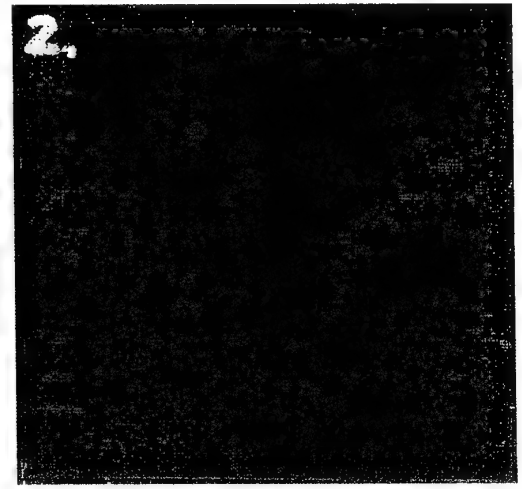


Plate # 2
Exposed to 100 °C dry environment for approximately 13 weeks.

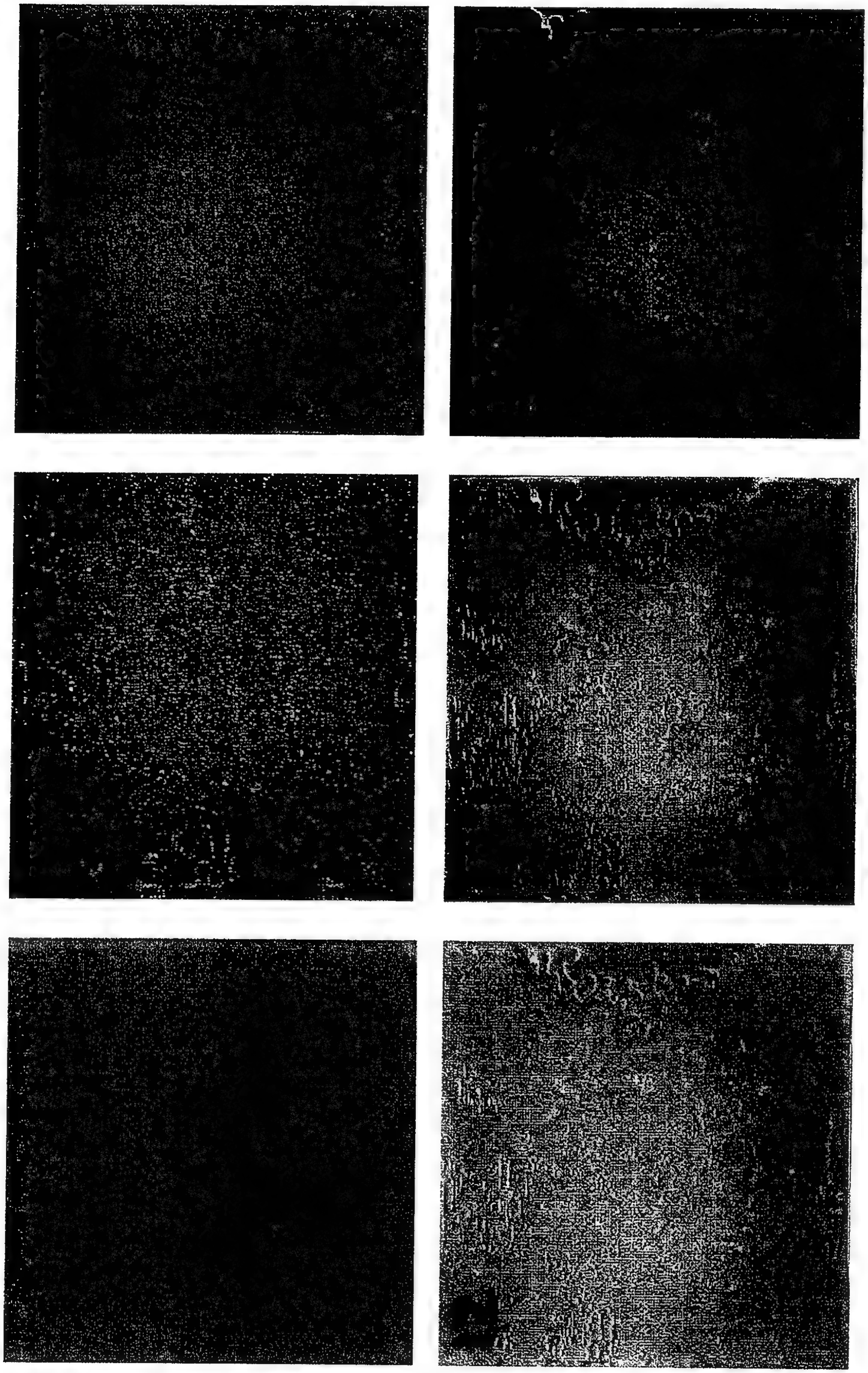


Plate # 12 Exposure to 70°C, 95 % RH: (Clockwise from top left) Reference, 4 weeks, 8 weeks, 16 weeks, 25 weeks & 36 weeks.

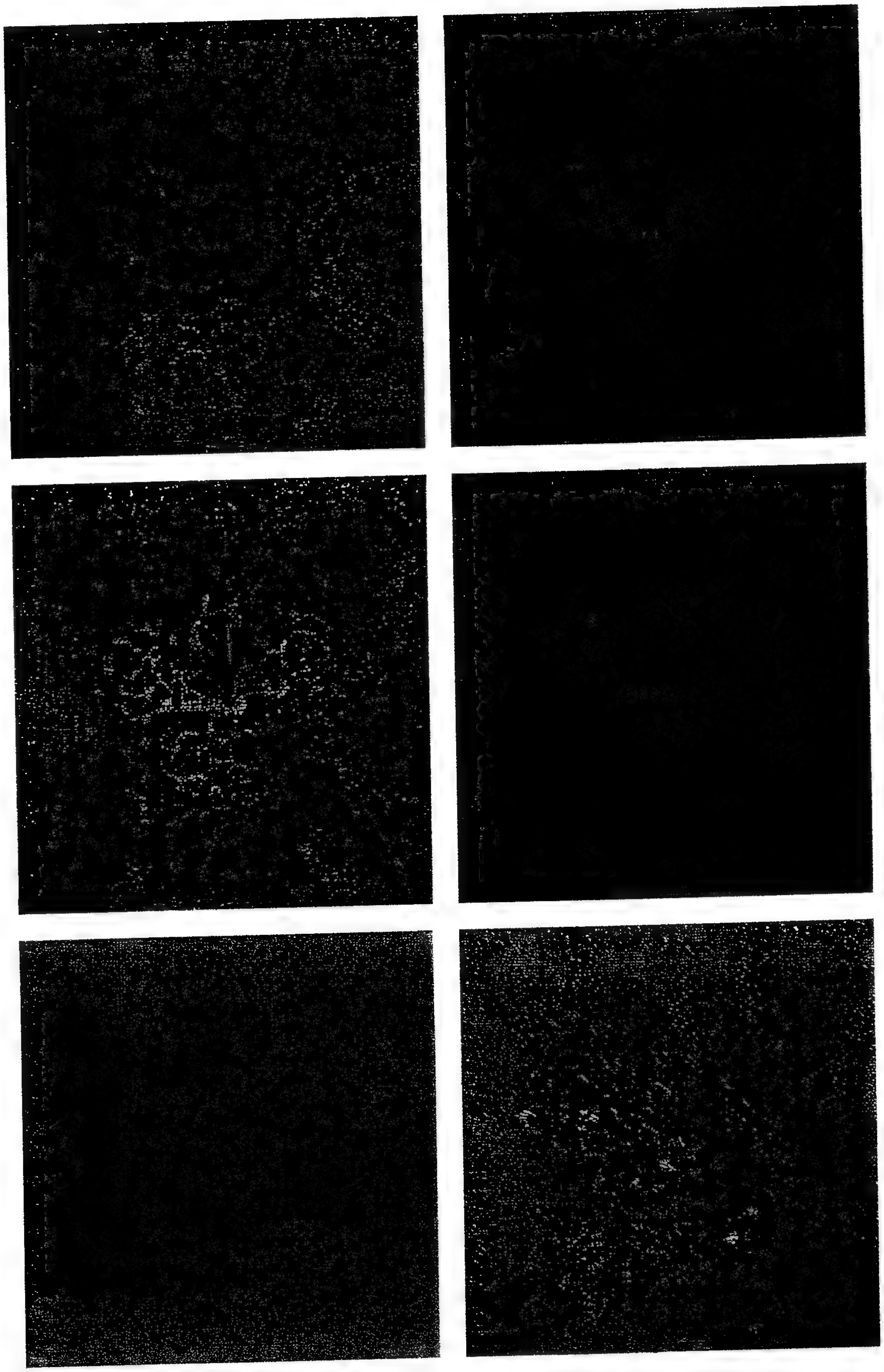


Plate # 14 Exposure to 70 °C, 85% RH: (Clockwise from top left) Reference, 4 weeks, 8 weeks, 16 weeks, 25 weeks & 36 weeks.

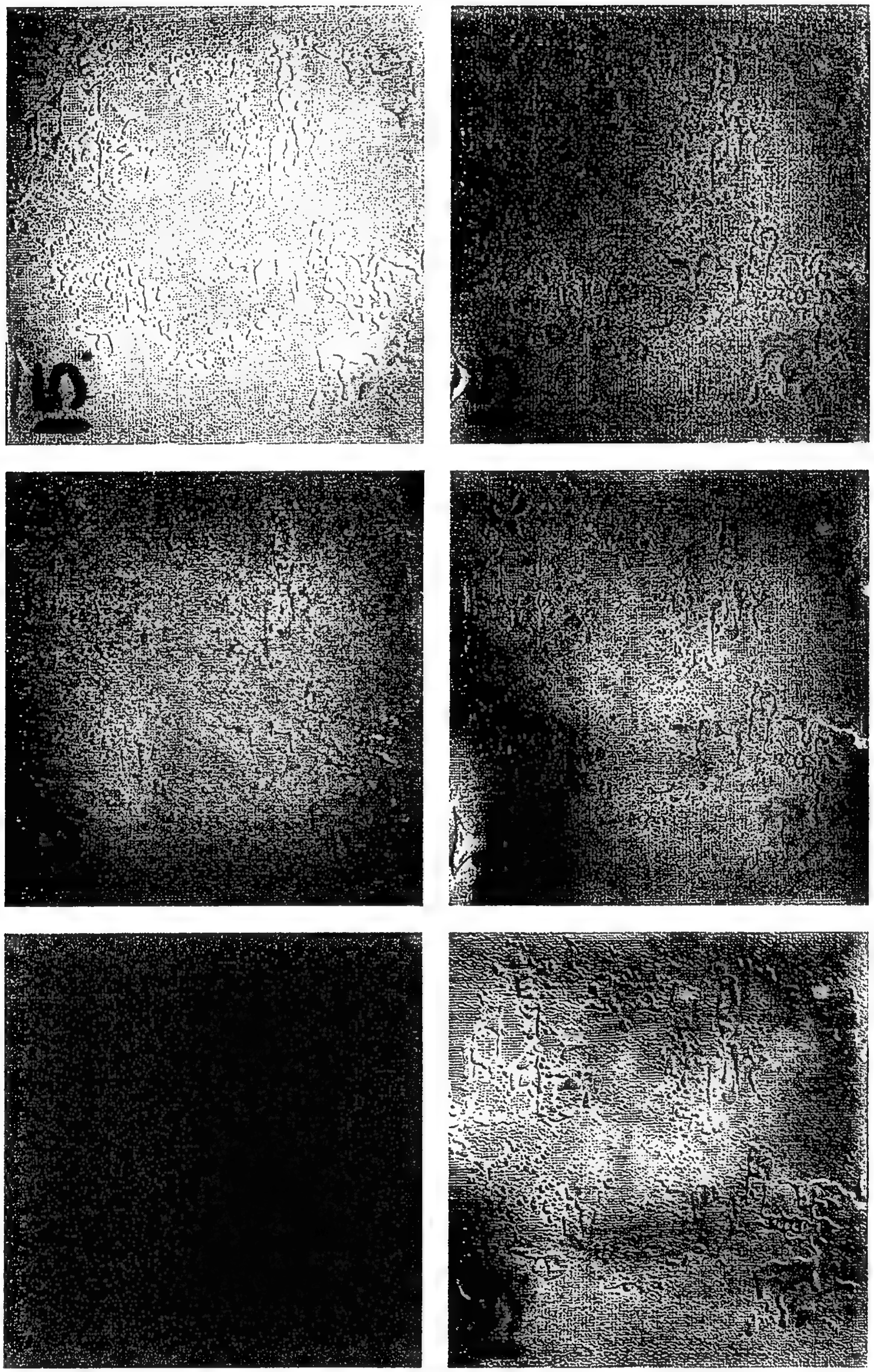


Plate # 15 Exposure to 80 °C, 95 % RH: (Clockwise from top left) Reference, 4 weeks, 8 weeks, 16 weeks, 25 weeks & 36 weeks.

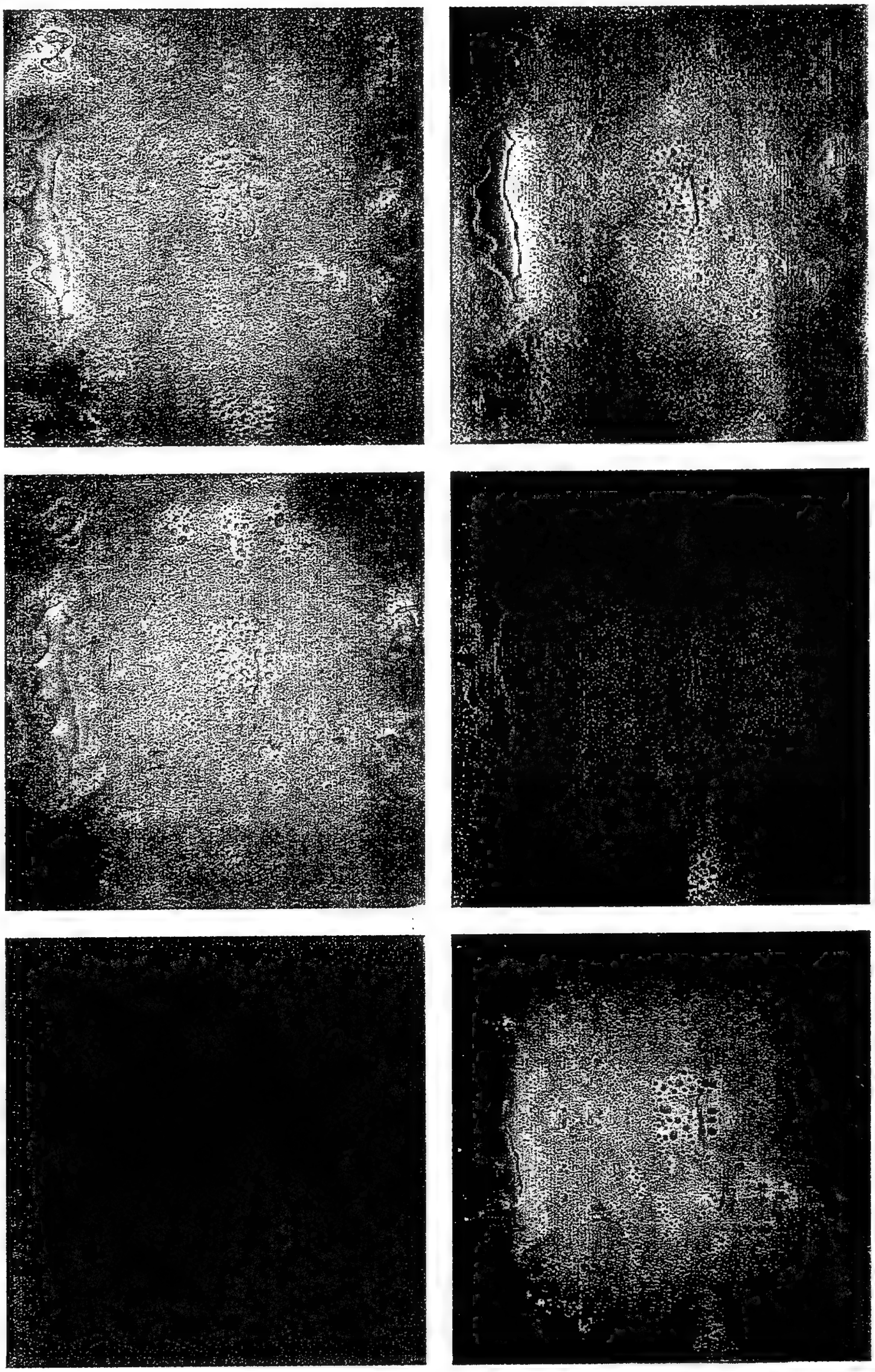


Plate # 16 Exposure Period to 90 °C, 95 % RH: (Clockwise from top left) Reference, 4 weeks, 8 weeks, 16 weeks, 25 weeks & 36 weeks.

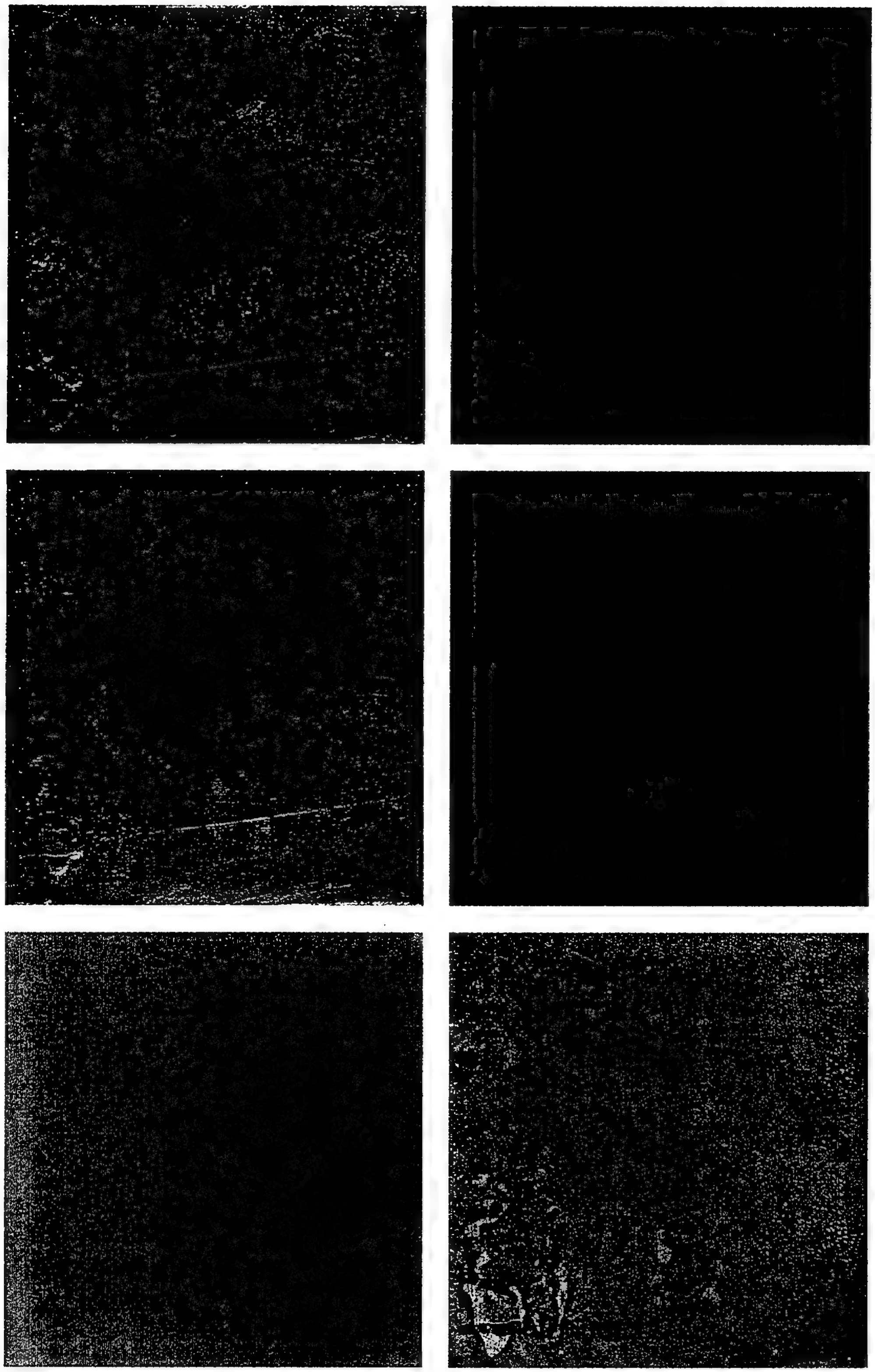


Plate # 17 Exposure Period to 90 °C, Dry : (Clockwise from top left) Reference, 4 weeks, 8 weeks, 16 weeks, 25 weeks & 36 weeks.

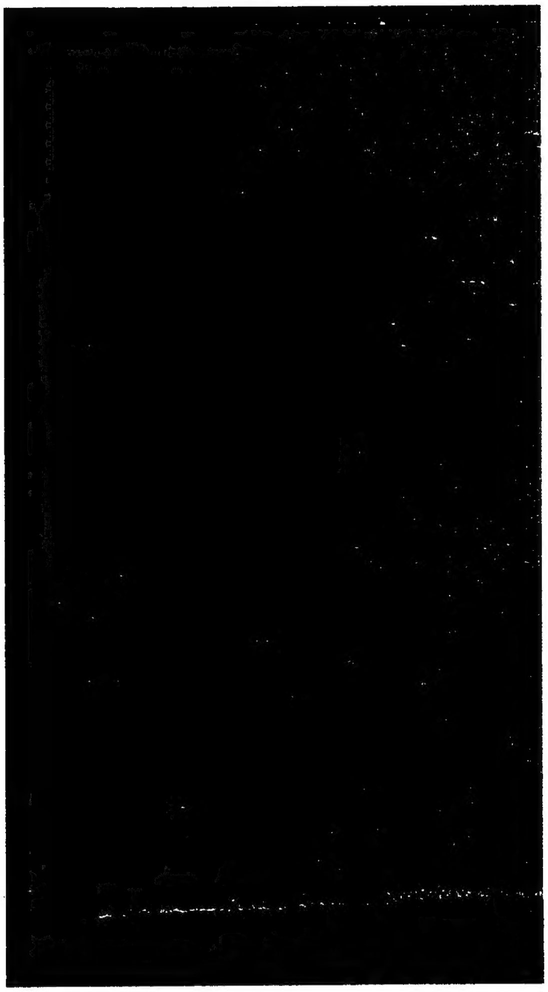


Plate # 9 (Edge exposure only)
Exposed to hot/dry environment at 100 °C for approximately 5 weeks.

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A. Charon

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19. ABSTRACT

Bonded honeycomb sandwich panels, consisting of graphite-epoxy face-sheets adhesively bonded to a honeycomb core, are used on military aircraft such as the F/A-18 due to their high stiffness and low weight. Cytec FM-300 is the adhesive extensively used in bonding these composite structures. Water entering these structures can seriously degrade the adhesive bonds between the skin and core and within the core itself. Such degradation poses an issue for structural integrity as shown by a recent study conducted at AMRL. It is often difficult to know whether the internal structure has had prior exposure to water as the structure may dry yet the bonds may be degraded. It has been observed that in some failed components the adhesive changes colour from its original post cure green colour to a light/dark brown. A laboratory experiment was conducted on Cytec FM-300 adhesive to assess the colour change after exposure to a range of hot/wet environments typical of aircraft service. It was found that the adhesive undergoes differing colour changes depending on exposure conditions. The light brown colour seen in some failed components was produced when the relative humidity was >95% and the temperature exceeded 90°C for an exposure period in excess of 20 weeks. The study concludes that Cytec FM-300 adhesive that has changed colour to a light or dark brown colour has been directly exposed to a hot/wet environment.